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August 19, 1980

Title: Underwater Patching Kit for Diving Suits.

Mr. Maxwell Lippitt, Jr.
Naval Coastal Systems Center
Code 712
Panama City, Florida 23406

Dear Mr. Lippitt:

This letter report describes our research efforts under Contract No. N61331-80M-1851 to develop a prototype patching kit for the underwater repair of torn dry diving suits.

INTRODUCTION

In a working diver's environment, dry diving suits sometimes snag on work surfaces and are torn. If this occurs in a cold water region, the diver's work may have to be delayed or aborted for safety reasons. A potential means of overcoming this problem would be to equip divers with a small repair kit that could be used underwater to patch a tear in dry suits. Recent advances in epoxy-polyamide chemistry enhance the feasibility of developing such a repair kit, since it has been shown that substituted accelerators such as amines can speed cure rates sufficiently to allow the necessary bonding action to take place underwater. Therefore, and as a follow-on to an earlier underwater-adhesive feasibility study, the U. S. Navy requested that the Battelle Columbus Laboratories undertake this project to develop a prototype underwater patching kit for use in repairing dry diving suits.

TECHNICAL DISCUSSION

Materials and Initial Observations

The suit material and epoxy formulation used in this project were recommended in a final report from Battelle to the U. S. Navy entitled "Feasibility of Developing an Underwater Patch Kit for Dry Diving Suits". The suit material was CF-200 crushed foam. The epoxy formulation was a two-part epoxy with the following proportional make-up:

Compound	Parts by Weight
Compound 1	
Epon 828	100
Compound 2	
Cap-Cure	100
DMP-30	10

Our initial effort consisted of becoming familiar with the mixing and handling characteristics of the epoxy. In doing so, we observed the following:

1. The epoxy mixture does stop water leaks in torn CF-200 material when a patch and epoxy mixture is prepared and applied to the tear underwater at 60°F. (It was noted that excess epoxy that enters the suit through the tear could possibly adhere to the diver's undergarments or skin.)

2. There is no apparent difference in adhesive characteristics between patches cured in fresh or in salt water.

3. Water introduced into the mixture at the time of mixing adversely affects the bonding action of the epoxy.

4. Precoating the patch with one compound and then later applying the second compound on top of the first, followed by kneading the patch, results in poor bonding action.

First Packaging Method

In our first packaging method, which paralleled the meat industry's "cold cut package" idea, the encapsulated compounds were sealed between a soft plastic top and a pliable patch of CF-200 below (see Figure 1). To use the kit, the diver would pop the compound capsules by squeezing them, then knead the whole kit until the compounds had mixed and the mixture had spread over the inside of the patch. To apply the patch, the diver would pull on the tabs, separate the patch from the plastic cover, and position the epoxy-coated CF-200 patch over the tear.

Although this concept is reasonable, the compounds did not handle as expected at low temperatures because (1) at low temperatures (32-40°F) the compounds become extremely viscous, resulting in an unreliable mixture; and (2) the poor mixture results in poor bonding action. (Battelle's Chemistry Section tried to improve the low temperature viscosities, but project funds limited these efforts.)

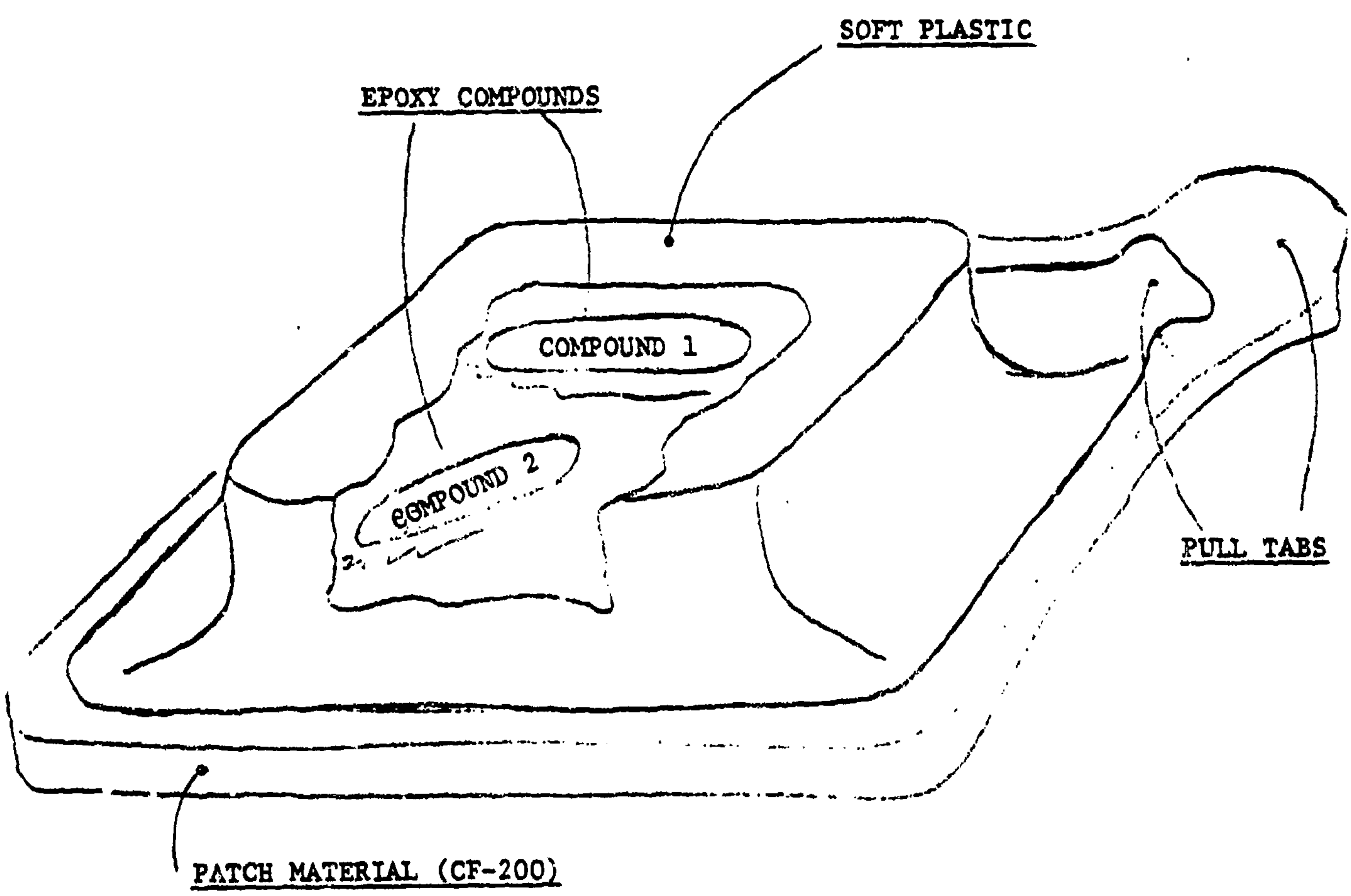

FIGURE 1. DIAGRAM OF FIRST PACKAGING METHOD

Second Packaging Method

Our second method provided more positive mixing of the compounds within a more compact enclosure. Called the "auger mixer", this repair method consists of the following items (see Figures 2 and 3):

1. A tube containing both epoxy compounds, which are kept apart by a thin plastic divider.

2. An auger blade at the end of a "T" handle.

3. An "O" ring around the handle stem to keep the water out of the epoxy mixture.

4. A removable cap to give the diver access to the mixed epoxy.

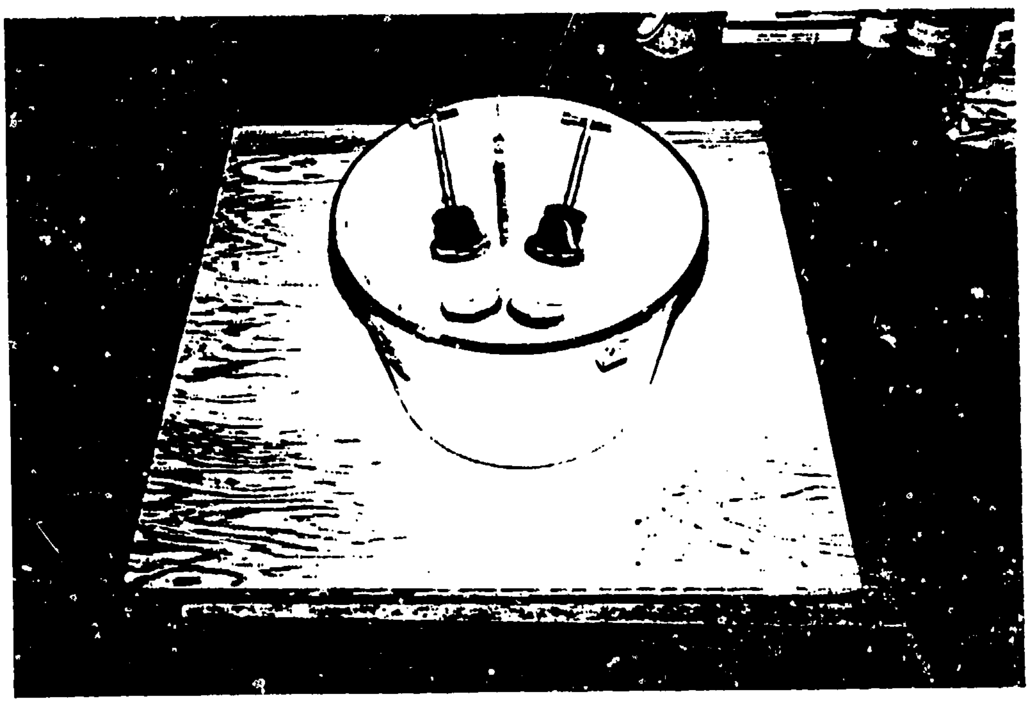

FIGURE 2. SECOND PACKAGING METHOD (AUGER MIXER)

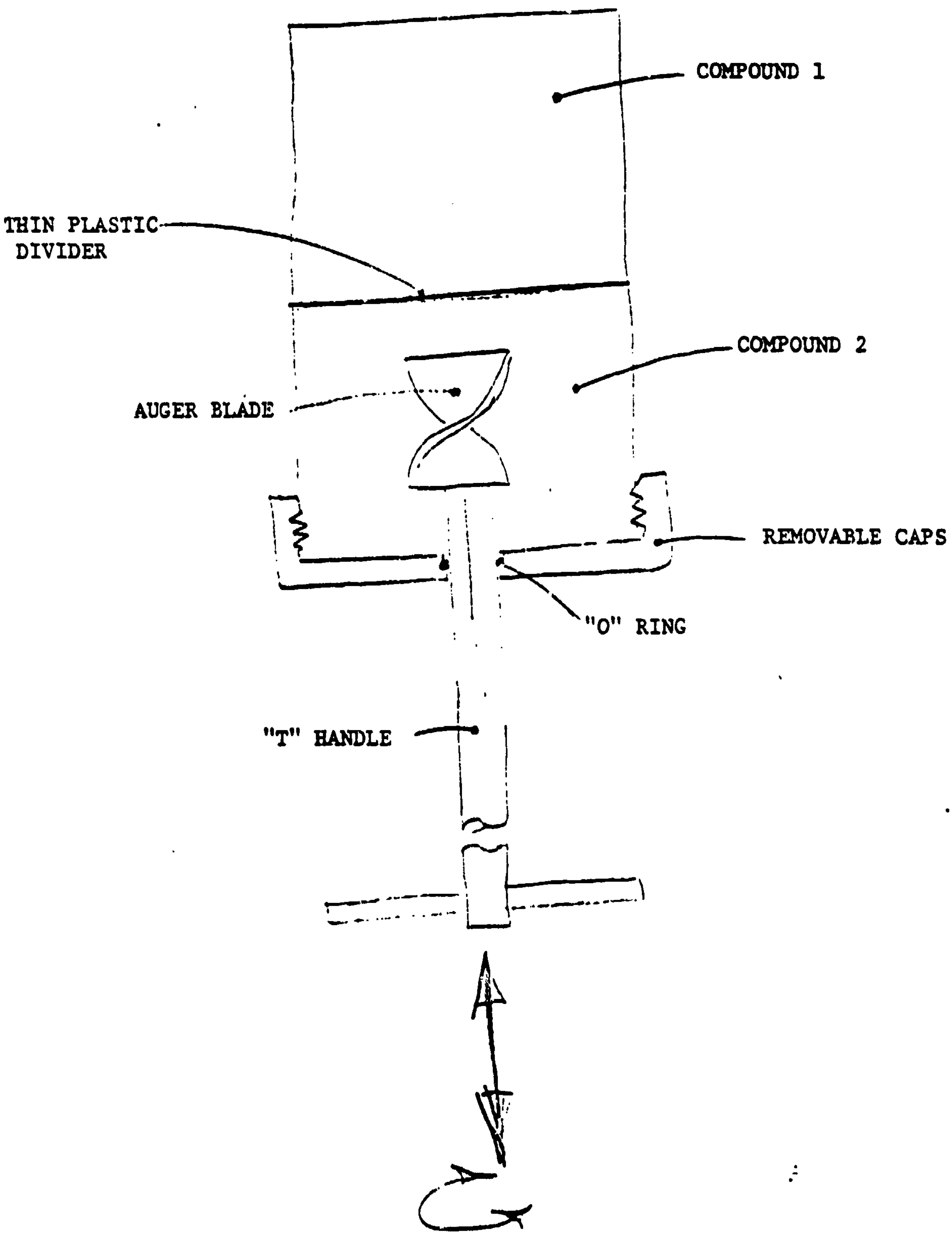

FIGURE 3. DIAGRAM OF SECOND PACKAGING METHOD (AUGER MIXER)

In this method, when a patch is needed, the diver (1) grips the tube with one hand and the "T" handle with the other; (2) pushes the auger blade through the plastic divider, thereby exposing the epoxy compounds to each other; (3) continues to rotate the "T" handle while at the same time pushing it in and pulling it out the full inside travel length of the epoxy tube; and (4), after the epoxy has been sufficiently mixed, unscrews the removable cap and, using the auger blade, removes however much mixed epoxy he needs to put on the patch material.

The compound tube consisted of 1.5-inch PVC male and female adapter traps with a 4-mm-thick plastic divider separating both cavities. PVC glue was used to join both adaptors. Fifty grams of Epon 828 was placed in the female adapter and 55 grams of Cap-Cure 3-800 plus DMP-30 was placed in the male adaptor; the auger blade cap was fastened to one end while a plain end cap was placed on the other end.

Testing and Evaluation of the Auger Mixer

Four water temperatures were chosen for testing the auger mixer: 60°F, 50°F, 40°F, and 32°F. The test parameters were adhesive strength versus curing time. A peel test was used to evaluate the adhesive strength of the bond; this involved 1-inch-strips of CF-200 patches that were bonded to the suit and then peeled off at a rate of 10 inch/min.

The laboratory test sequence for a patch specimen consisted of:

1. Cooling the compound-filled auger mixer and patch/suit materials in salt water at the test temperatures for 1.5-2 hours.

2. Mixing the epoxy in salt water at the test temperatures for 2 to 3 minutes.

3. Applying the epoxy mix to the patch underwater.

4. Placing the patch on the suit underwater.

5. Allowing the patch/suit bond to cure underwater at test temperatures, with 1.5 psi applied pressure.

6. Subjecting the patch/suit specimen to the peel test after its having cured for a preset period of time.

Figure 4, which shows the resulting peel loads (lbs) versus cure time (min) for patch/suit specimens at the four temperatures, indicates:

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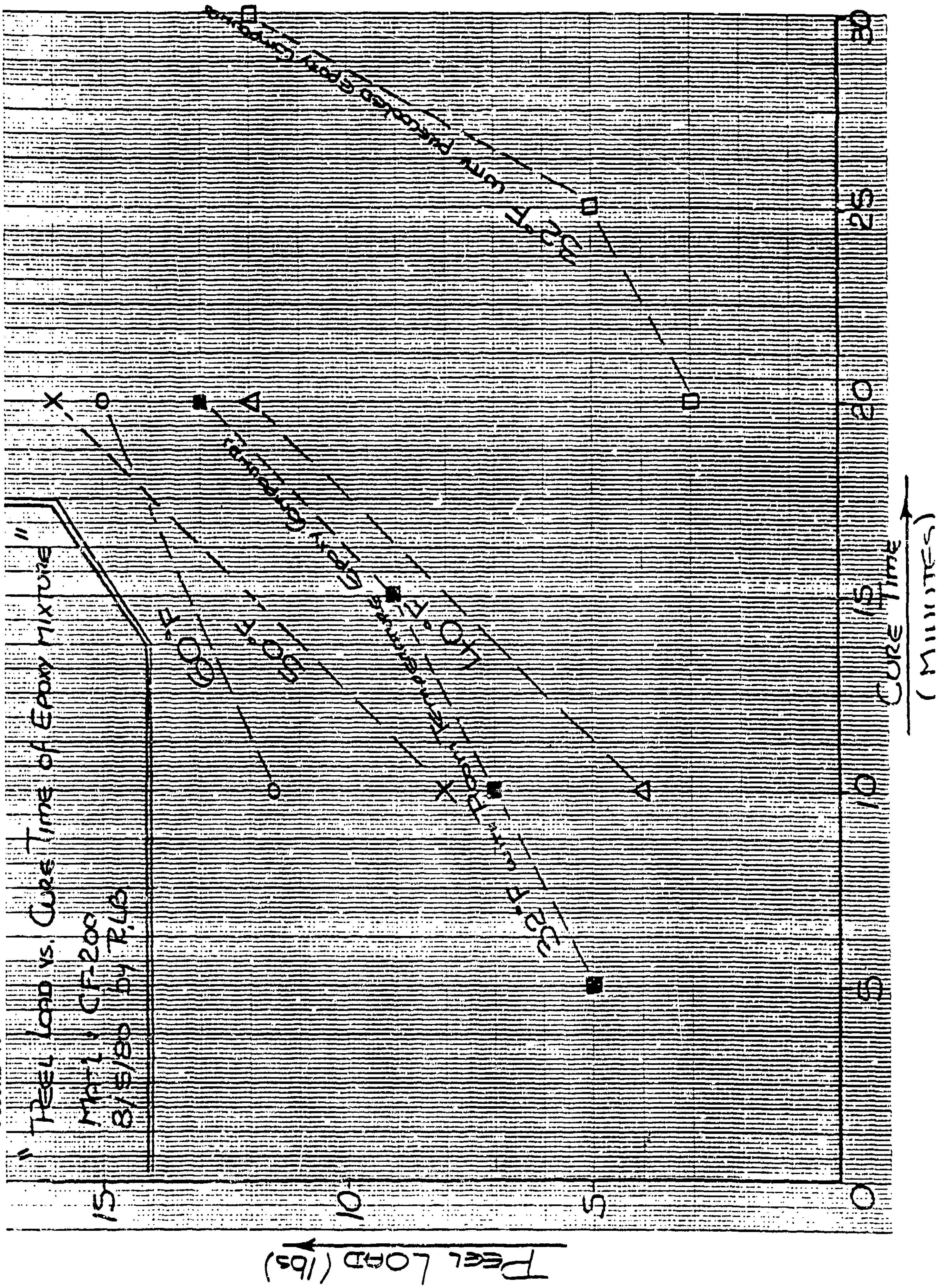
FIGURE 4.



1. The longer the cure time at any one temperature, the stronger the bond. In the case of the 40°F test, for example, doubling the cure time (from 10 to 20 minutes) nearly tripled the peel loads (from 4 to 12 lbs).

2. Temperature, as expected, influences bond strength: the colder it is, the longer it takes to cure the specimen bond. For example, to get approximately 11 lbs of peel load, 10 minutes of cure time was required at 60°F; 14 minutes at 50°F; 19 minutes at 40°F; and 30 minutes at 32°F.

In a subsequent attempt to reduce the curing time at low temperatures (especially 32°F), one change was made in the laboratory test sequence: rather than precooling the epoxy compounds to the test temperatures, the epoxy was mixed at room temperature (approximately 70°F) and then applied per the laboratory test sequence. Under these conditions, the bond strength gain was significant: whereas 30 minutes of curing time was required to generate 12 lbs of peel load in the 32°F test, only 20 minutes was required for 13 lbs of peel load in this modified 32°F test run.

In an actual diving situation, this method could be implemented in two ways:

1. The patch kit, with a thin layer of insulating material around it, could be kept topside. Upon request from the diver, a "warm" kit could be send down for underwater use.

2. If properly insulated, the kit could be carried by the diver to his work site. Even if the ambient water was cold, the contents of the insulated patch kit would remain warmer.

Finally, in an effort to ensure that the actual diving suit with its seam and recessed area could be patched with the CF-200 patch/epoxy system, room temperature patches were applied to cuts made in the hood and crotch of the suit. These patches adhered well to the contoured surface areas and remained flexible.

CONCLUSION

The epoxy patch kit system developed in this project is effective, providing the bond has sufficient time to cure. Because a diver can not be expected to stop work for extended periods of time in cold water to allow the patch bond to set, a patch retainer such as Velcro straps could be used, whenever possible, to hold the patch in place while the diver goes about his work.

RECOMMENDATIONS

Unless an entirely different patching system for dry diving suits is developed, the epoxy formulation investigated in this project should be modified for easier and more thorough low-temperature mixing and for a shorter curing period. Such modification would allow the packaging of the adhesive to be simplified.

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Thank you for your help and cooperation in this project. We have enjoyed working with you, and look forward to working with you again.

Sincerely,

D. V. Fink for R. L. B.

Roger Brunel
Project Engineer
Equipment Development Section

RLB:djs